INFRASOUND SIGNAL LIBRARY

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Sponsored by National Nuclear Security Administration
Office of Nonproliferation Research and Engineering
Office of Defense Nuclear Nonproliferation

Contract No. DE-AC04-94AL85000[1] and W-7405-ENG-36[2]

ABSTRACT

The United States conducted over 100 atmospheric nuclear tests at the Nevada Test Site (NTS) from 1951-1962. Beginning with Operation Buster, Sandia National Laboratories (SNL) deployed infrasound sensors to record the air waves across the southwestern United States. In addition, some tests in the South Pacific were monitored, as well as numerous chemical explosions. A typical test was recorded at about a dozen stations from the Control Point on the Nevada Test Site (NTS) to as far away as Pasadena, California. The strip charts registered signals in the frequency band from 0.05 to 30 Hz, and the paper tapes of this data were eventually stored in the archives at Sandia. The NTS atmospheric shots ranged in yield from below 1 ton to 74 kilotons; source altitudes varied from near ground level (including some cratering experiments) to as high as 11 km. More recently, Los Alamos National Laboratory (LANL) has operated infrasound stations in New Mexico and Utah for many years. Over that time, they recorded explosions at White Sands Missile Range and elsewhere, as well as several bolides. The LANL stations provide continuous digital signals, with the earlier data from them recorded on 9-track magnetic tapes. The SNL and LANL archives contain a wealth of information on the source function, yield scaling, weather effects, and regional propagation of infrasound signals from atmospheric explosions. International interest in infrasonic monitoring for the Comprehensive Nuclear-Test-Ban Treaty (CTBT) verification has prompted us to explore these collections and retrieve and digitize numerous recordings. For the NTS events, our initial focus has been on yield scaling and altitude effects. We have selected several low-altitude NTS tests spanning a wide range in yield, as well as the few available high-altitude shots. We will attempt to read the LANL magnetic tapes and transfer their contents to CD-ROM. Once the various signals are in a usable digital form, we will convert them to the established NNSA schema, along with relevant event and station information. The resulting database tables and binary waveform files will be made available to the research community. Where appropriate, the information will be included in the Knowledge Base (KB) under development by the National Nuclear Security Administration (NNSA).

OBJECTIVE

The International Monitoring System (IMS) under construction for the verification of the Comprehensive Nuclear-Test-Ban Treaty includes a network of infrasound stations designed to detect atmospheric explosions. An increasing number of infrasound stations around the world are collecting pressure signals from a wide assortment of atmospheric events and phenomena. However, relatively few records are available for kiloton-size atmospheric explosions, the yield range of greatest concern for CTBT monitoring, because atmospheric testing was discontinued in the early 1960's. Sandia Corporation (subsequently Sandia National Laboratories) recorded pressure signals from most of the atmospheric tests conducted by the United States prior to the Limited Test Ban Treaty, primarily to determine the potential for off-site property damage. The signals at several stations across the Southwest were recorded on strip charts. The paper charts were subsequently stored in Sandia's archives. We have initiated an effort to retrieve many of these records, digitize them, and assemble a 'ground-truth' collection of digital infrasound waveforms from atmospheric nuclear tests of known location, time and size. In addition to this collection, Los Alamos National Laboratory (LANL) will provide infrasound data on a variety of events recorded by their stations since the 1980's. These stations have recorded acoustic signals from several underground tests at the Nevada Test Site (NTS), conventional explosions at White Sands Missile Range, regional earthquakes and bolides. The LANL data include both paper records and 9-track digital tapes. The set of recordings that we assemble will be converted to a standard format and made available to the infrasound research community.

RESEARCH ACCOMPLISHED

Atmospheric Testing at NTS

The U.S. began nuclear testing at the NTS in January 1951. Until the Limited Nuclear Test Ban Treaty (LTBT) outlawed atmospheric testing in 1963, the majority of shots at NTS were conducted above ground. The Department of Energy's list of 'Announced United States Nuclear Events' includes over 100 tests detonated on or above the ground surface. Figure 1a shows the number of such events by year, and Figure 1b shows the number by month. The announced yields of these tests ranged from below 1 ton (*e.g.*, LASSEN) up to 74 kt (HOOD).

The Blast Prediction Unit at Sandia

Atmospheric nuclear tests at NTS in the early 1950's occasionally resulted in the damage to some buildings in Las Vegas and other surrounding communities. Most of the early damage claims filed against the Atomic Energy Commission involved broken windows and cracked plaster. Even this relatively minor damage was unexpected, based on anticipated pressures for the yields and distances involved. Such effects in Las Vegas jeopardized continued operations at NTS. A Blast Prediction Unit (BPU) was formed at Sandia in 1951, and tasked with collecting pressure data from subsequent tests, determining the cause of the damaging pressures, and improving predictions of pressure amplitudes (Reed, 1974).

The first step for the BPU was to develop an infrasound recording system, or microbarograph, suitable for recording a very wide range of overpressures and operating in a variety of environments (Sandia Corp., 1953). The resulting system employed a twisted Bourdon tube pressure sensor, with an adjustable bleed plug for controlling the low-frequency response. As with modern infrasound stations, an array of porous hoses helped to reduce noise from localized turbulence. An adjustable amplifier boosted the sensor signal, then a variable bandpass filter removed noise outside the desired frequency band. The low-frequency cutoff could be set at 0.01, 0.03, 0.1 or 0.3 Hz, and the high-frequency cutoff at 1, 3, 10 or 30 Hz. The filter output went in parallel to two more amplifiers, which resulted in high-gain and low-gain signals with an amplitude ratio of 4. Finally, a strip-chart recorder wrote the signals onto paper tape, along with a timing code. This chart usually ran at 25 mm/sec; pressure at full deflection of the pen (±20 mm) varied from 4 μb to 48 mb, depending on the amplifier setting. Under optimal conditions, the designers believed the system could detect pressure signals as small as 1 μb.

For a typical NTS atmospheric shot in the fifties, the BPU operated approximately 12 infrasound stations in Nevada, Utah and California (Figure 2). Six of these were 'dual stations' with 2 sensors separated by about 1 mile along a line from NTS. These stations measured phase velocities of the wavefronts. This helped in identifying arrivals and provided information on the structure of the upper atmosphere. Several tests in the South Pacific were monitored as well. These were generally larger than the NTS events, so the stations would be installed at greater ranges. All stations were manned during the tests. One-ton chemical explosions were detonated 1-2 hours prior to each test, to check on the actual propagation conditions and assist the selection of gains. Recording began prior to the shot time, and extended for several minutes past the time of the first arrival. The resulting paper tapes were many meters in length, so they were cumbersome to reproduce. Because of this, the original tapes are the only existing copies of the raw data from these operations.

During the 1960's, and particularly after signing of the LTBT in 1963, acoustic signals from a wider variety of sources were investigated. The BPU recorded many of the larger underground tests. The Plowshare program conducted numerous cratering experiments, using both nuclear and chemical explosions. Studies of sonic booms from aircraft were conducted for National Aeronautics and Space Administration (NASA) and the Air Force, and of signals from underwater high-explosive (HE) explosions for the Navy. HE shots were also used to improve the understanding of source altitude effects, upper atmosphere propagation and surface reflections. In 1974, all available microbarograph records entered the permanent retention archives at Sandia. Reed (1974) provides an overview of the archive contents along with brief comments on the various experiments that were conducted.

Infrasound Data Collected by Los Alamos

Over the duration of the LANL infrasound program a few unique datasets have been collected with direct relevance to explosion monitoring. To date, these datasets have had limited utility due to their format (paper records and/or magnetic tapes with archaic formats). We have selected three of these datasets as candidates for conversion to a standard digital format.

The old AFTAC infrasound network was in operation from 1950-1974 and consisted of 12-25 stations, depending on the recording date. In addition to atmospheric explosions, the network recorded many other types of events, including bolides. Bolides represent the most important impulsive natural event for infrasound, and such events may not be detected by other technologies. Approximately 20 years ago LANL acquired from AFTAC a set of bolide recordings from a limited number of network stations. In all, there are about 100 records. Unfortunately, these recordings are on paper strip charts (digital recording technology was not available) so their utility has been limited. As with the Sandia BPU data, we propose to digitize these records and convert them to established NNSA schema to make them available for analysis and for comparison with events recorded by the IMS infrasound network.

A second LANL dataset of direct use for explosion monitoring is a set of infrasound observations from large-scale explosive tests sponsored by the Defense Nuclear Agency (DNA). These tests used ammonium nitrate and fuel oil (ANFO) as the charge, covered charge weights of 24 – 4,880 tons of ANFO, and were executed from 1981-1993 at White Sands Missile Range (WSMR) in southern New Mexico. The recordings are from permanent stations at Los Alamos, NM, St. George, UT and the NTS, including 2 - 4 mobile stations per event. These recordings represent recent infrasound measurements of kiloton size explosions, and would be similar to the source size of interest in the current era of nonproliferation monitoring. Regrettably, due to the older computer platforms, these data are not in an easily recoverable electronic form. Fortunately, paper records are available for all of the events and these could be digitized and converted to established NNSA schema using the same methods and technology discussed below.

Finally, LANL also has a large number of the data collection tapes from the higher frequency infrasound arrays at St. George and Los Alamos. These tapes hold continuous recordings, not triggered or segmented and so they contain an unknown number and variety of events. In this case electronic media is available, but as 9-track magnetic tapes that are becoming increasingly difficult to read. Fortunately, we believe that Sandia still has the equipment to read these 9-track tapes and will extract the data. We plan to pull from this collection the tapes that would have data on specific events of interest: ANFO events, earthquakes, bolides, underground tests and other impulsive events.

Digitizing the Signals

In preliminary efforts to retrieve pressure signals from the SNL archives, we assessed the quality of the recordings and put together a digitizing system capable of effectively handling them. In general, the archived strip charts are in excellent condition, and have neither faded nor become brittle in the 40+ years since they were produced. Each of the nearly 15,000 tapes was annotated with the shot, station and channel names, along with information on the system gain and filter settings. Every tape includes both high- and low-gain signals, along with a timing signal with 1-second intervals. Reference timing pulses were added to the signals at the shot time and at 5-minute intervals until the end of the recording, so the locally-generated 1-sec time code can be calibrated with reasonable accuracy. Most of the charts used a recording speed of 25 mm/sec. All began recording before the shot time and the most distant stations in California and Utah continued until about 1200-sec after the shot, in order to capture signals returned from the thermosphere. Individual charts were as long as 30 m, making them inconvenient either to reproduce or to digitize on a standard digitizing table. Instead, we are using a digitizing system originally developed for use with well logs. It employs a continuous-feed gray-scale scanner, which generates a digital image of each chart. Figure 3 shows a portion of the scanned image of a record from the station in Indian Springs, NV for the NTS shot HORNET on March 12, 1955. In this case, the high-gain signal (top trace) clipped at the beginning of the first arrival, while the low-gain trace remained on-scale. Also evident in the figure is the curvature of the amplitude axis caused by the 70-mm length of the pen arm, and we will correct the final digitized signals for the effects of this curvature.

Once a scanned image of a chart is available on the computer, we digitize the signals using a commercial software package from Neuralog, Inc. This program can correct for skewed axes as well as both minor warping and drift along the time axis. The user first defines the time and amplitude axis for the program, then initiates digitization of a trace by clicking on a few points at its beginning. After this, the software attempts to automatically follow the signal along the graph. In general, this process works quite well and saves considerable time. However, it occasionally wanders off the signal, a problem most frequently encountered with faint or high frequency traces. Because of this, the operator must diligently monitor the digitizing process, and occasionally intervene to assist the software through troublesome portions of the record. The software includes some tools to scan the digitized trace and mark certain types of potential errors, such as spikes or inconsistent timing. Once the signals have been satisfactorily digitized, time and amplitude values are written to a file using a specified sampling rate, along with header information and comments entered by the operator. Finally, we will convert the data in these text files to standard binary '.w' files with associated wfdisc database records, as used by the NNSA Knowledge Base.

Representative Data

Initial efforts with the Sandia data on NTS atmospheric tests are focused on providing information on yield scaling and altitude effects. For the first of these, we are digitizing pressure signals from several shots which cover a wide range in source size, as given in the Department of Energy's list of 'Announced United States Nuclear Events'. The selected events were primarily detonated atop a tower, typically 300-500 ft off the ground. Yields range from below 1 ton (LASSEN, 6/5/57) to 43 kt (TURK, 3/7/55). To minimize the effects of seasonal winds, we will concentrate on the events conducted during the spring for this set of data. In addition, the closer stations (*e.g.*, the Control Point (CP) on NTS and Mercury, NV) should be less affected by variations in atmospheric conditions, so these may prove most useful for establishing yield scaling over the available range. Figure 4 shows a record section constructed from the digitized signals from HORNET, 3/12/55. Peak overpressures range from 7.5 mb at CP to 0.1 mb at Las Vegas, NV. Note in the figure that the stations in California and Utah, at distances beyond 200 km, observed stronger arrivals than the Nevada stations approximately 150 km from the source. This is consistent with standard models of acoustic velocity *vs.* altitude, which predict a 'first bounce' return from the stratosphere at a distance of approximately 200 km (see Gutenberg, 1951, Fig. 14).

To address the effects of source altitude on the acoustic arrivals at surface stations, we will retrieve as much data as we can from the few high-altitude NTS tests. The highest of these was HA, 4/6/55, a 3-kt test at an altitude of 36,600 ft. Other NTS tests were detonated at altitudes of 20,000 ft (JOHN) and 1500 ft (several). If feasible, we will also digitize the signals from high-altitude tests over the Pacific, most notably YUCCA at 86,000 ft. The signals from these events should provide useful information for constraining the equivalent yields of bolides and large meteors that sometimes catastrophically disintegrate high in the atmosphere thus, behaving somewhat like concentrated explosions (Chyba *et al.*, 1993). Bolides are likely to represent one of the more common types of impulsive events recorded by the IMS infrasound network, and pose some concern as sources of false alarms.

CONCLUSIONS AND RECOMMENDATIONS

The SNL and LANL collections of pressure signals can provide valuable data for addressing some current research issues in infrasonic monitoring. They contain records from a wide variety of atmospheric events, including nuclear tests, conventional explosions, sonic booms, and bolides. The signals span a similar frequency band to that of the IMS infrasound network. We are digitizing some of the old paper records and we will attempt to extract the available digital data from the magnetic tapes. The data we collect will be converted to a common format, then distributed to the monitoring research community.

REFERENCES

Chyba, C. F., P. J. Thomas and K. J. Zahnle (1993), The 1908 Tunguska explosion: atmospheric disruption of a stony asteroid, *Nature*, 361, 40-44.

Cox, E. F. and J. W. Reed (1957), Long-distance blast predictions, microbarometric measurements, and upper-atmosphere meteorological observations for operations Upshot-Knothole, Castle, and Teapot, *Report* WT-9003, Sandia Corporation, Albuquerque, NM.

Gutenberg, B. (1951), Sound propagation in the atmosphere, in *Compendium of Meteorology*, T. F. Malone (ed.), American Meteorological Society.

Reed, J. W. (1974), Archiving guide to microbarograph records of nuclear and chemical explosion tests, *Report* SLA-74-0210, Sandia Laboratories, Albuquerque, NM.

Sandia Corp. (1953), Microbarograph evaluation report, *Report* SC-2990 (TR), Sandia Corporation, Albuquerque, NM.

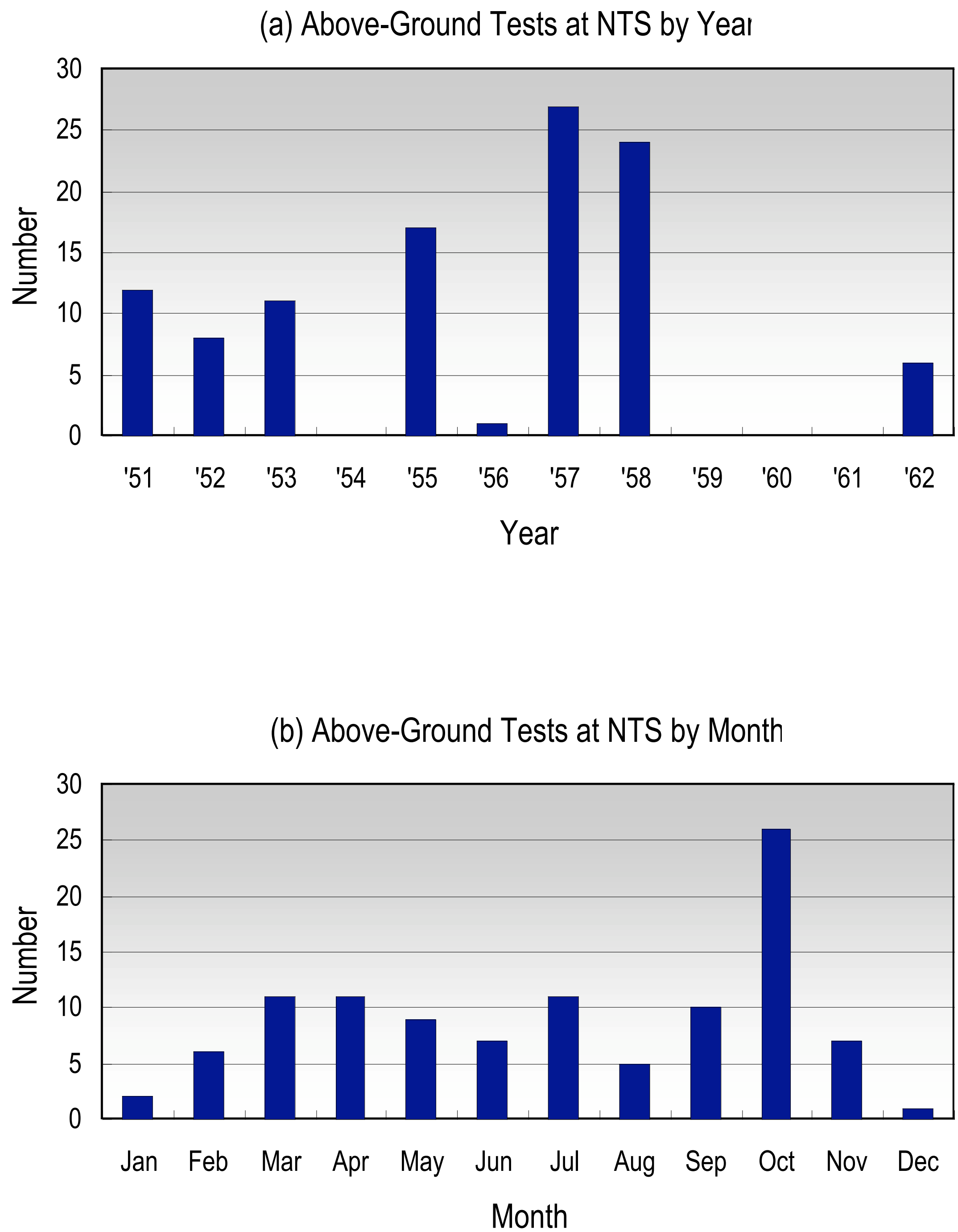

Figure 1. Distributions of announced NTS above-ground tests by year (a) and month (b).

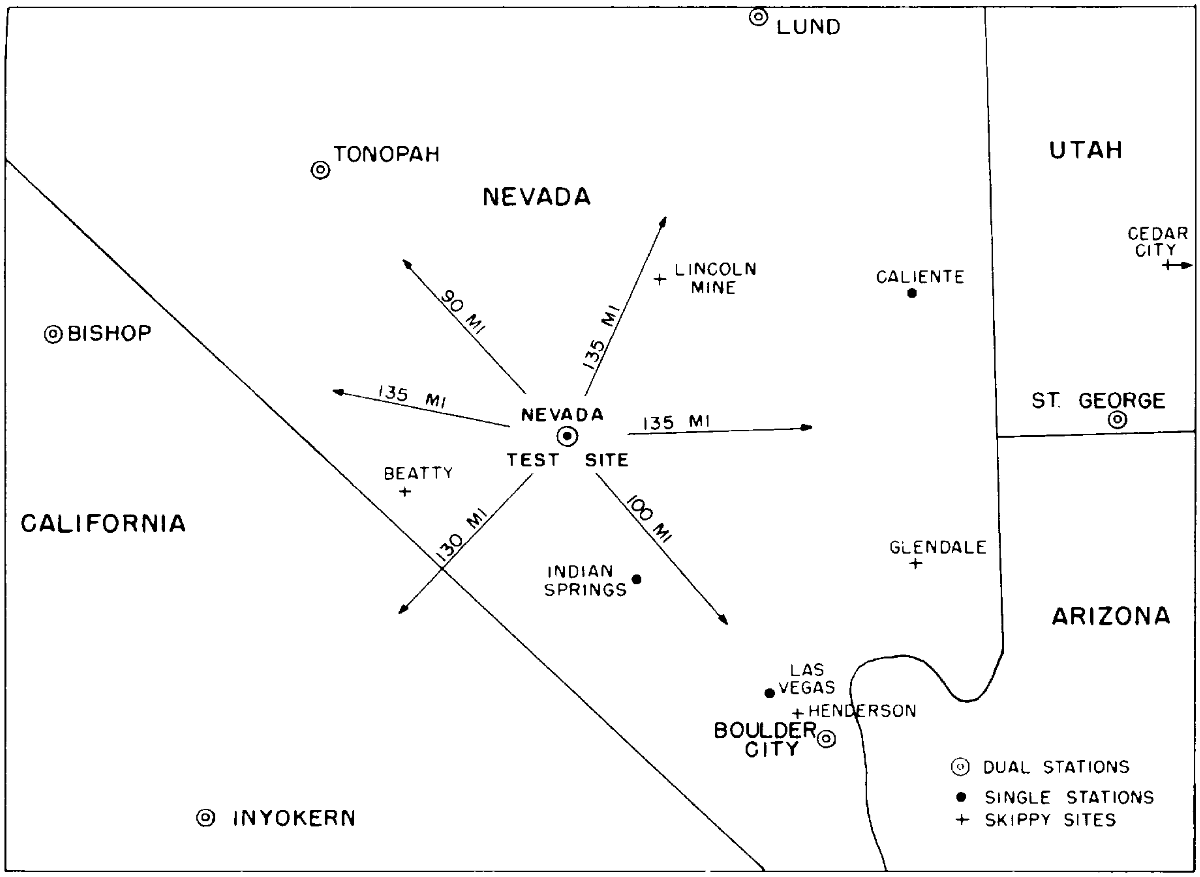

Figure 2. Map of microbarograph station locations used during 1955 (Cox and Reed, 1957).

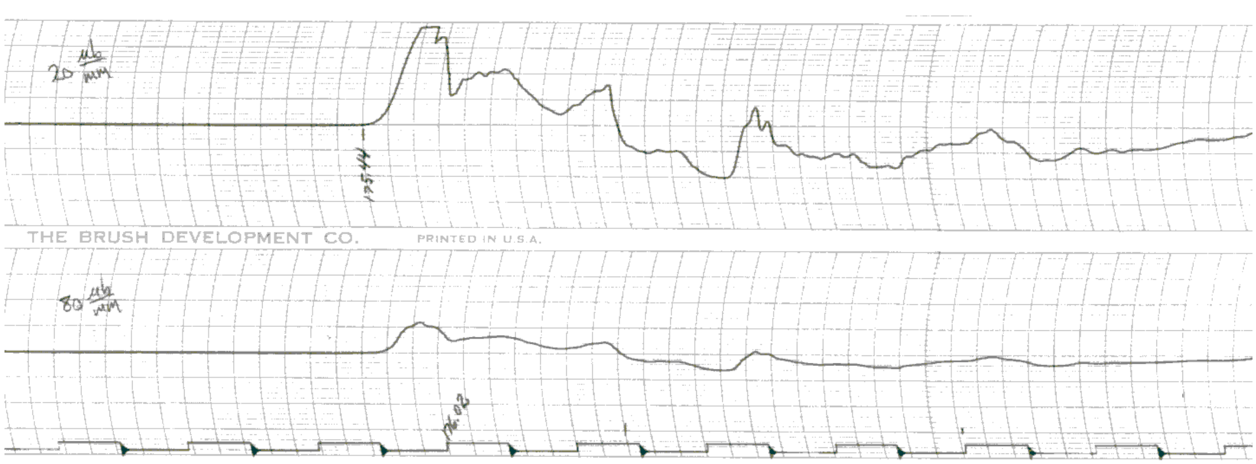

Figure 3. A portion of the strip chart from Indian Springs, NV for the NTS test HORNET, 3/12/1955.

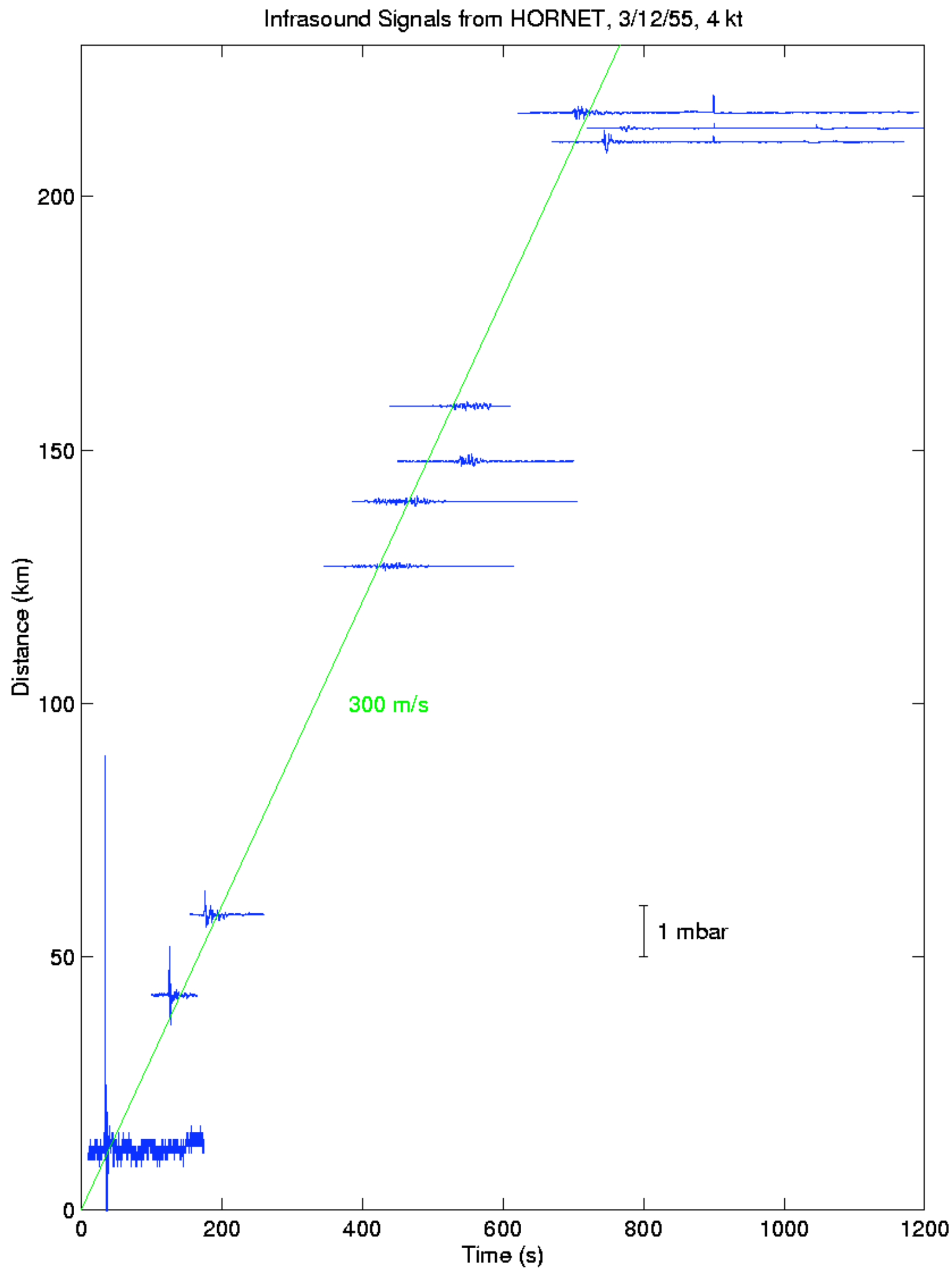

Figure 4. Record section of the pressure signals from HORNET.